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Petrographic Criteria for the Recognition of 'Magadi-Type' Cherts

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ABSTRACT

The Magadi cherts, inorganic lacustrine deposits from the Lake Magadi area, Kenya, are widely used as a modern analog to explain the origin of ancient inorganic cherts. Formed in a highly alkaline lake, as the result of a transformation from the sodium silicates minerals, magadiite and/or kenyaite, to quartz, the Magadi cherts possess a distinctive set of textural characteristics that allow them to be distinguished from cherts of different origin with only a limited number of samples. Textural characteristics that are diagnostic of the Magadi cherts and that can be used as a test for the occurrence of ancient 'Magadi-type' cherts are: 1) groundmass textures, which lie on a continuum from equigranular mosaics to grid-works, 2) variable concentrations of groundmass inclusions which occur as washes, clots, and fragments, 3) morphology, location, and orientation of cracks, fenestrae, and their filling phases, and 4) crystal molds. The transformation from magadiite to chert is accompanied by a 25% volume loss which is accomodated by the formation of shrinkage cracks, both internal and external, most similar in morphology and infill to subaqueously formed shrinkage cracks in clays and concretions, respectively. Textural and paragenetic criteria appear to be a valid test for the presence of 'Magadi-type' cherts. Because important paleoenvironmental interpretations are made based on the presence of 'Magadi-type' cherts, it is important to have diagnostic tests to aid in its recognition. Further field work, and comparisons with lacustrine cherts of intermediate age are clearly needed at this point.

ACKNOWLEDGMENTS

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My research pursuits have been aided by a number of individuals. X-ray diffraction machines were made available by Drs. Annabelle Foos, University of Akron, and Donald Lindsley, State University of New York at Stony Brook. Scanning electron microscope and sputter coating facilities were provided by Drs. David Egloff and Ming Chou, from Oberlin College and Case Western Reserve University respectively. I would like to thank Dr. James Aronson, Case Western Reserve University, for the sample which he so diligently searched for.

I would like to thank all of the people who stood by my side, both in person and in spirit, providing the support and encouragement necessary to perservere through the good times and the bad. You all know who you are. Most of all I would like to thank my parents for supporting my personal and professional goals throughout my educational career.

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STATEMENT OF THE PROBLEM

What is the origin of chert?

The origin of chert, a microcrystalline variety of quartz, has perplexed geologists for many years. Ronov (1964) found that the nature of the chert can generally be correlated with age and occurrence of the deposit. Bedded cherts are most important in association with Precambrian iron-formations and shales, while the nodular cherts are more commonly found in association with Phanerozoic carbonates. The change in dominant bedding style may reflect a change in depositional style during earth history. Chert formation can be divided into two broad categories: 1) inorganic precipitation, and 2) biogenically driven formation. Overlap between both the processes and products of these two categories makes it important to study all aspects of a deposit so that proper determinations relating to its origin can be made. Inorganic origins have been inferred for cherts from numerous locations around the world, representing all periods of geologic history. The most abundant, and least understood, are the bedded cherts found in the Precambrian iron-formations. Geochemical changes, in particular changes in the earth's atmosphere and hydrosphere, may be reflected in part, by the different mechansims responsible for chert formation during earth history.

Cherts occur locally in Pleistocene strata of the Lake Magadi area, Kenya. Eugster (1967, 1969, 1980), Eugster and Kelts (1983) and Hay (1968) have postulated an inorganic pathway to explain these cherts, although they invoke different mechanisms to account for the transformation from sodium silicate minerals (magadiite and/or kenyaite) to quartz. This origin has been inferred for ancient lacustrine cherts from: Oregon (Sheppard and Gude, 1974), Scotland (Parnell, 1986), and Wyoming, Utah, and Colorado (Surdam et al., 1972). Eugster and Chou (1973) also extended this concept to explain the cherts in Precambrian iron-formations. A better understanding of recent inorganic chert precipitates is necessary to test the proposed inorganic origin of these ancient siliceous deposits.

RESEARCH ACTIVITIES AND METHODS

I undertook a predominantly petrographic study to document the textural characteristics of the type Magadi cherts. Most of the data came from transmitted light microscopy, backed up by X-ray diffraction (XRD) data, cathode luminescence (CL), and scanning electron microscopy (SEM) data. Where feasible I established paragenetic sequences within the samples I studied. Comparison with the presumed presursor material (magadiite-$NaSi_7O_{13}(OH)_3 \cdot 3H_2O$) served to elucidate changes in crystal morphologies that took place as a result of the transformation. Finally, I compared the textural characteristics of the Magadi cherts with proposed ancient analogs, and cherts of other presumed origins, to see if petrography can be used as a test for recognizing 'Magadi-type' cherts.

Nine samples from the High Magadi Beds were then analyzed by XRD between 5°- 75° at 0.020 degrees per second. Scanning electron microscopy provided detailed information about the sizes, shapes and organizations of individual crystallites. Samples were prepared in several different ways. Some freshly broken surfaces were etched in hydroflouric acid, either stock (52-55%) or diluted (10%), while others were left unetched. Thin sections were also studied via SEM.

GEOLOGY OF THE LAKE MAGADI AREA, KENYA

General Geologic Setting

The Magadi Basin is located in the eastern Rift Valley of Kenya (Fig. 1). Lake Magadi, found at the low point in a long narrow fault trough, is the most alkaline of the highly alkaline (sodium carbonate-bicarbonate) lakes located in the eastern Rift Valley. The walls of the fault trough are trachyte lava flows, erosion of which may be a significant source of sodium in the lake.

Water passes through a number of stages en route to the lake. Perennial streams and ephemeral runoff are two sources of dilute waters which feed the ground water system. Waters can flow through either the shallow or deep ground water system, surfacing in hot springs, which feed the peripheral brine pools and ultimately the lake. There is no direct inflow of water into Lake Magadi, because the stream waters enter the ground water system before reaching the lake. Streams that are responsible for supplying the waters to Lake Magadi are found on the steeper, western margin of the basin (Fig. 2)(Baker, 1958; Eugster, 1980).

Evolution of the brines in Lake Magadi is controlled largely by evaporative concentration. Hardie and Eugster (1970)

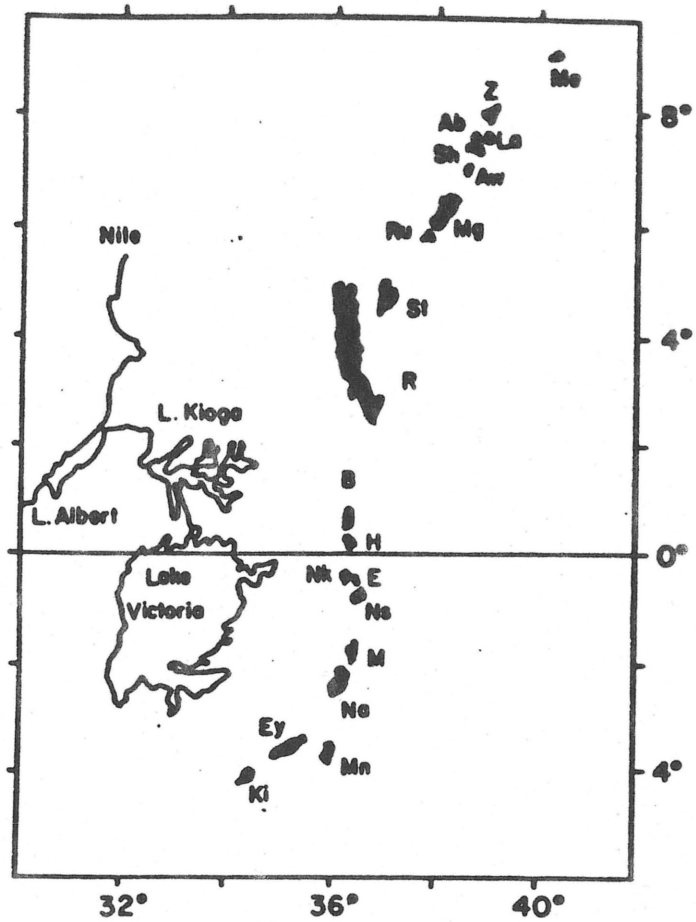


Figure 1. Closed basins in the Eastern Rift Valley of Ethiopia, Kenya, and Tanzania. From north to south they are: Me-Metahara, Ab-Ablata, La-Langano, Sh-Shale, Aw-Awassa, Mg-Margherita, Ru-Ruspoli, St-Stephanie, R-Turkana, H-Bogoria, Nk-Nakura, E-Elmenteita, Ns-Naivasha, M-Magadi, Na-Natron, Mn-Manyara, Ey-Eyasi, and Ki-Kitangiri (from Eugster, 1980).

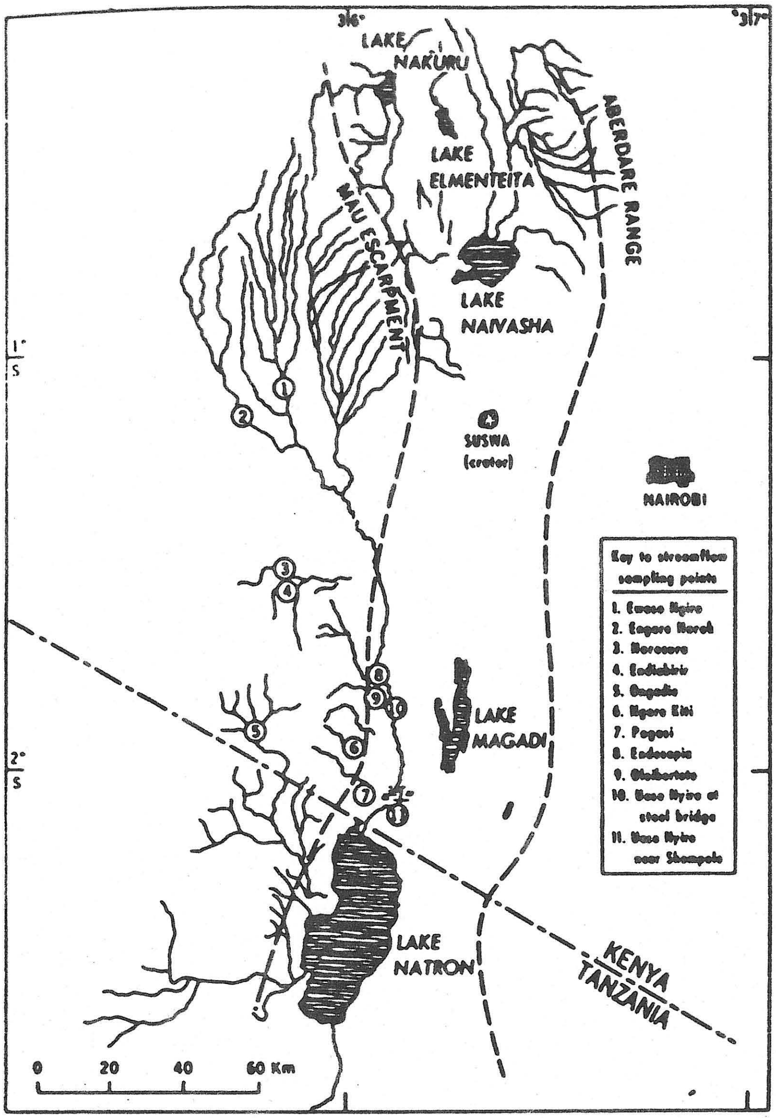


Figure 2. Sources of inflow from perennial streams between Lake Nakuru and Lake Natron (Jones et al. 1977). Streams 8,9, and 10 are important sources for Lake Magadi. Dashed lines show the boundaries of the rift valley (from Eugster, 1980).

presented a model of brine evolution based on the principle of chemical divides (Fig. 3). Given the concentrations of a given set of solutes in dilute source waters, it is possible to trace the path of probable mineral precipitation and brine composition through time. The alkaline earths in the Lake Magadi Area are largely removed by precipitation of carbonates induced by capillary evaporation in the subsurface, while surface evaporation is the predominant controlling factor in brine evolution between hot springs and the lake brines.

Stratigraphy of the Magadi Basin

The sediments in the Magadi Basin have been divided into five stratigraphic units. These units are, from oldest to youngest: 1) plateau trachytes, 2) the Oloronga Beds, 3) trachyte lava flows, 4) the High Magadi Beds, and 5) the Evaporite Series (Table 1 and Figs. 4 & 5)(Baker, 1958;Eugster, 1980). Other workers (Hay, 1968; Baker, 1958) divided the High Magadi Beds into two units, the High Magadi Beds and the Chert Series. Eugster, however, interpreted the chert beds to be time equivalent with the magadiite deposits, on the basis of lateral transitions between magadiite and chert in a single near-surface bed, so combined the two units.

Trachyte lava flows are present above and below the Oloronga Beds. Eleven laterally continuous lava sheets have been documented in the Lake Magadi area (Baker, 1958). These lava flows are uniform in both composition and thickness throughout the basin, with a medium greenish to brownish grey fine-grained groundmass and three generations of sodium-rich anorthoclase

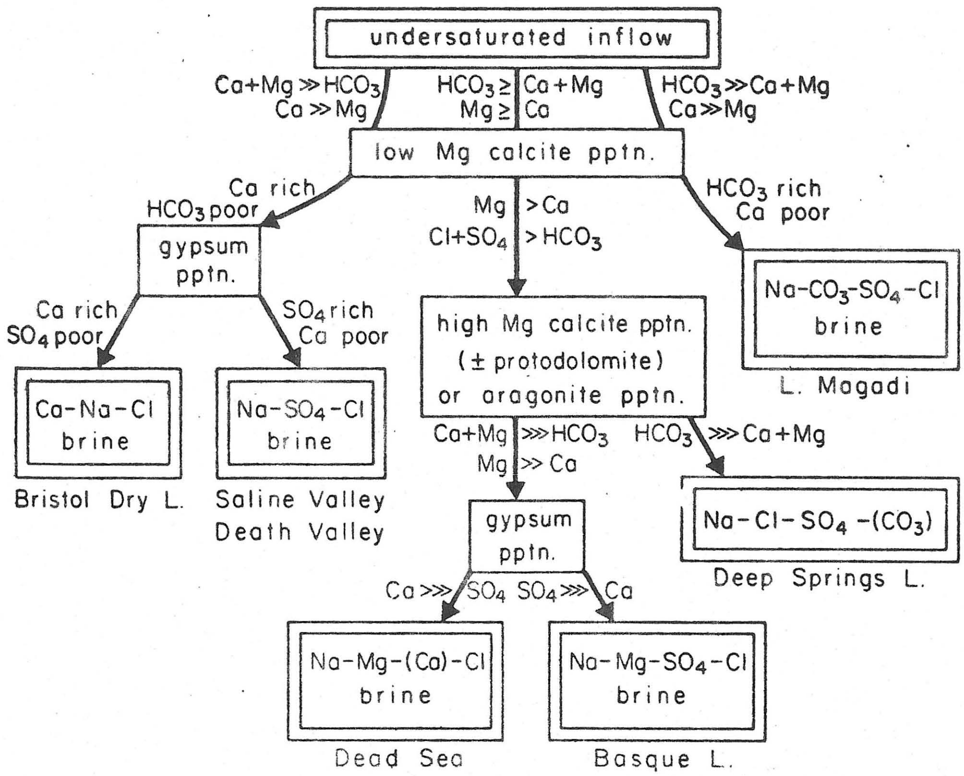


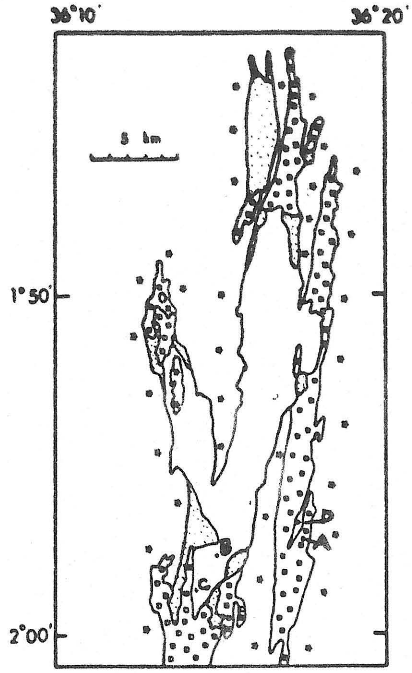
Figure 3. A flow chart representing possible paths of brine evolution by evaporative concentration (from Hardie, Smoot, and Eugster, 1977).

TABLE 1

STRATIGRAPHY OF THE LAKE MAGADI AREA

UNIT (distinguishing feature)	AGE, YEARS
Evaporite Series (slight tilting)	0
High Magadi Beds (minor faulting)	9100 (Butzer et al., 1972)
Trachyte flows (Kunkar limestone)	780,000 (Fairhead et al., 1972)
Oloronga Beds (grid-faulting)	
Plateau trachytes	up to 1,300,000,000 (Baker and Mitchell, 1976)

(from Eugster, 1980).



Location A - Samples 233A & B, 234, &234B

Location B - Samples 249A, B, C, D, E, F,

Location C - Samples 251 A & B

Location D - Sample 313 (magadiite)

Figure 4. Sketch map of Lake Magadi (from Eugster, 1980). Stars-trachyte flows, open squares-Oloronga Beds, solid squares-High Magadi Beds, dots-Lagoons, open-trona.

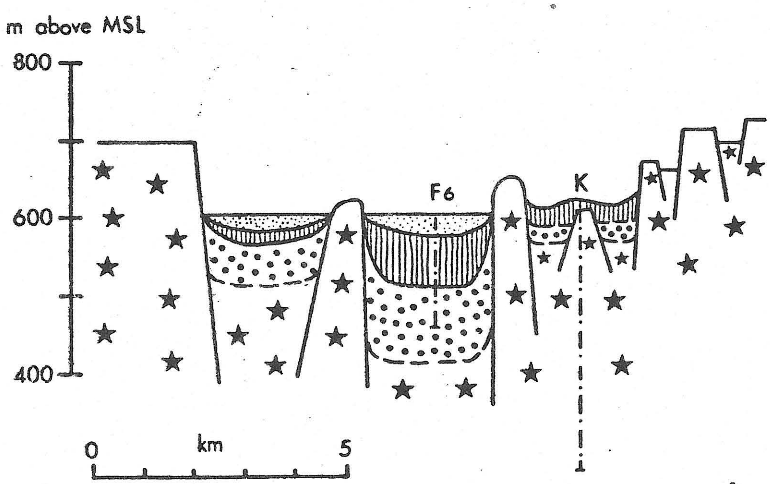


Figure 5. Cross section through Lake Magadi, vertical exaggeration of 1500 (from Eugster, 1980). See figure 4 for the key to the symbols.

phenocrysts (Baker, 1958).

The Oloronga Beds consist of dominantly fine-grained volcanigenic sediments and cherts, capped by caliche up to 50 cm thick.

The High Magadi Beds consist mainly of clay- and silt-sized volcanigenic sediments, and cherts. They can be divided into an upper and lower portion. The upper portion of the High Magadi Beds is composed primarily of poorly bedded volcanigenic silts. This sequence is relatively thick (4 m), and has a characteristic knobby weathering pattern. The lower sequence is characterized by chert horizons and magadiite horizons that are finely interbedded with volcanic clays. Near the top of the lower portion of the High Magadi Beds is a prominent marker, the _Tilapia_ bed. This 2-10 cm thick layer of laminated clays contains a high concentration of carbonized blackfish skeletons. _Tilapia_ _Nilotica_ is similar to a species that is currently found living in the more dilute lagoon waters around Lake Magadi. Chert beds, usally less than 50 cm thick, are common throughout the drill cores. Magadiite beds are also common throughout the sequence. The uppermost magadiite bed, from 5 cm to 65 cm below the _Tilapia_ layer, is 50-60 cm thick in the center of the basin and thins towards the edges of the basin. The magadiite bed splits into several thinner (1-2 cm) beds near the basin edge. A 1-3 cm thick continuous chert layer lies directly under the base of this magadiite bed.

The Evaporite Series comprises extensive deposits of the evaporite mineral trona ($Na_2CO_3.NaHCO_3.2H_2O$) that are forming throughout the present Lake Magadi and are the youngest deposits in the basin. Trona deposits of up to 48 m thick have been recorded, but are interrupted by thin beds of tuffaceous clays (Hay, 1968).

DESCRIPTION OF THE MAGADI CHERTS

Mineralogical composition of the Magadi cherts

In decreasing order of abundance, the six phases identified in the Magadi cherts are: 1) quartz, 2) calcite, 3) analcime, 4) albite, 5) siderite, and 6) illite. Six of the eight samples analyzed were predominantly quartz with minor impurities (Table 2). Other cherts have a larger proportion of calcite, siderite, albite, analcime, and/or illite impurities. Volcaniclastics are a minor component in the samples I studied. Sample M-251, however, from location C (Figure 4), has a large volcaniclastic component, predominantly small euhedral to subhedral feldspar phenocrysts, but still displays many of the features that characterize the other Magadi cherts. Impurities occur as large crystals or smaller, mostly clay-sized, particles scattered throughout the samples. Finely disseminated impurities are a minor but widespread component of the samples. Mineralogical categories are, in decreasing order of abundance: 1) quartz, 2) carbonates, 3) zeolites, and 4) silicate clays.

Textural description of the Magadi Cherts

Samples from the High Magadi beds can be divided into three components: 1) groundmass, 2) cracks and fenestrae, and 3) crystal molds, based on their mineralogical components and associated textures. I will discuss each of the three zones and

TABLE 2

MINERALOGICAL COMPOSITION OF ANALYZED SAMPLES

SAMPLE #	LOCATION	SAMPLE CHARACTERISTICS	PHASES PRESENT
M-233C	A	Equigranular mosaic of chert	Q with minor s & ab
M-233P	A	Powdery inclusion-rich outer surface	Q, a, ab, s, & il
M-234	A	Inclusion-rich ground-mass chert	Q, a, il
M-234S	A	Inclusion-poor material from sample surface	Q with minor c, & ab
M-234B	A	Inclusion-rich ground-mass chert	Q with minor c, ab, & il
M-249BC	B	Inclusion-rich ground-mass chert	Q with minor il, c, a, & ab
M-249BG	B	Groundmass cherts from edge of the sample	Q
M-251	C	Inclusion-rich ground-mass chert	Q with minor c & ab
M-251C	C	Euhedral carbonates, in trains on sample surfaces	C with minor Q

q-quartz c-calcite a-analcime ab-albite s-siderite il-illite

Note: All samples are from the High Magadi Beds. See figure 4 for locations.

their associated textures in the following sections.

Groundmass

The bulk of the chert samples from Lake Magadi consist of equigranular mosaics of quartz crystals with variable admixtures of finely disseminated impurities. These cherts, referred to here as groundmass, show textures that can be placed along a continuum based on crystal orientation and extinction behavior. The two end-members of the continuum are: 1) randomly oriented crystals, and 2) crystals organized into a rectilinear grid-work, which is readily visible between crossed polars with the gypsum plate inserted (Fig. 6A, B). The extinction units in randomly oriented mosaics are approximately equal in size, ranging from 10-80 m. Individual extinction units exhibit sweeping extinction, reminiscent of a disorganized or relict fibrous habit.

Cherts with the grid-work fabric sometimes show a dominant, but rarely pervasive, crystallographic orientation. Extinction units in sections with the grid-work orientation are often elongate, ranging in size from approximately 10 to 50 μm in the long direction and between 6 and 15 μm across. Equant units, also present in the grid-work cherts, are generally smaller, with cross-sections of approximately 10-30 μm. Preferential alignment of quartz c-axes in two mutually perpendicular directions produces the grid-work appearance. Under the SEM, extinction units appear as a series of light and dark patches which consist of groupings of one or more quartz platelets (Figs. 7A & B). Extinction in the grid-work cherts is sweeping, but less so than in the mosaic cherts. Crystallites show a decreasing degree of

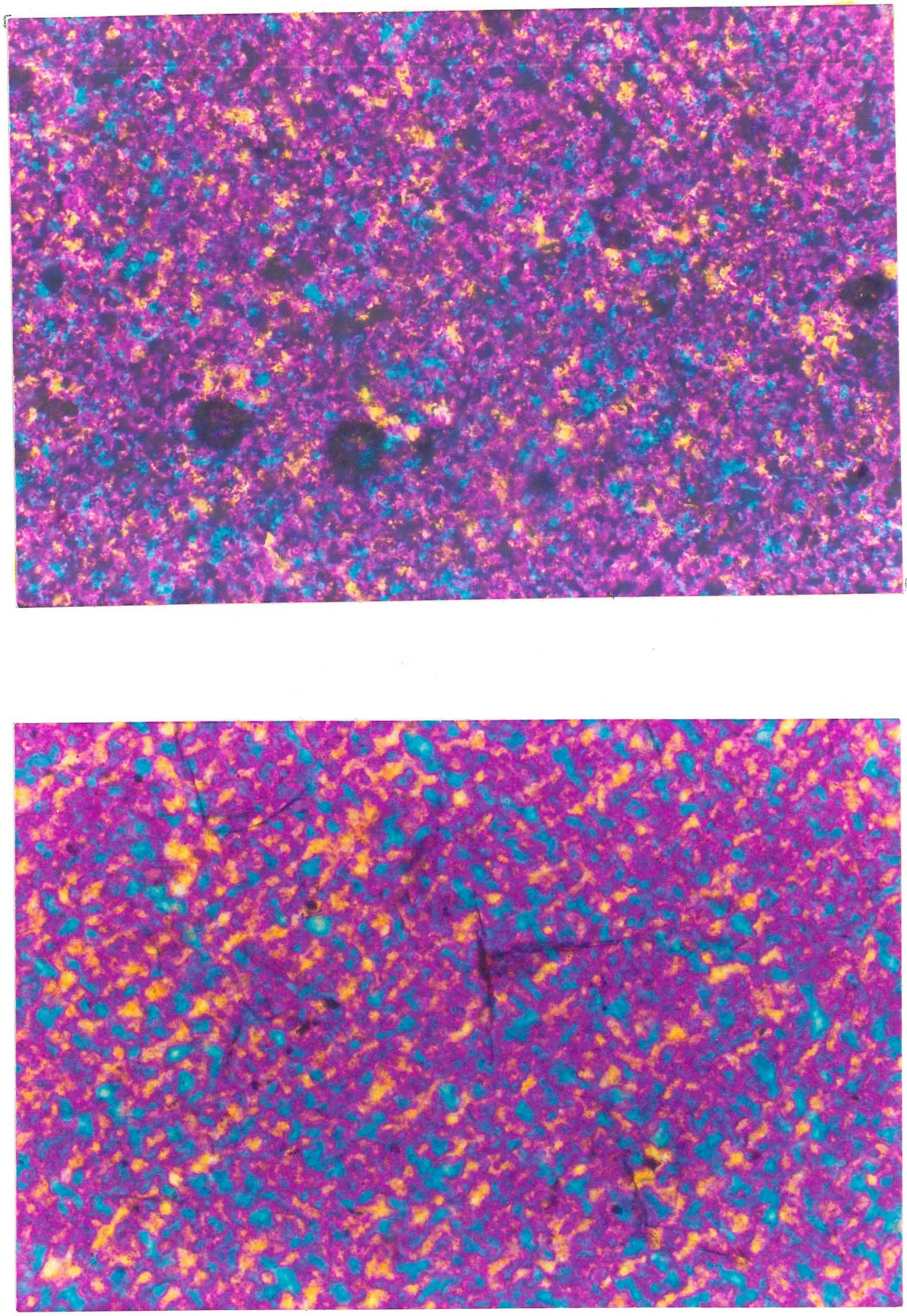


Figure 6. Two end-members of the groundmass textures. A) Mosaic crystal orientation, and B) the rectilinear grid-work fabric. Cross-polars with gypsum.

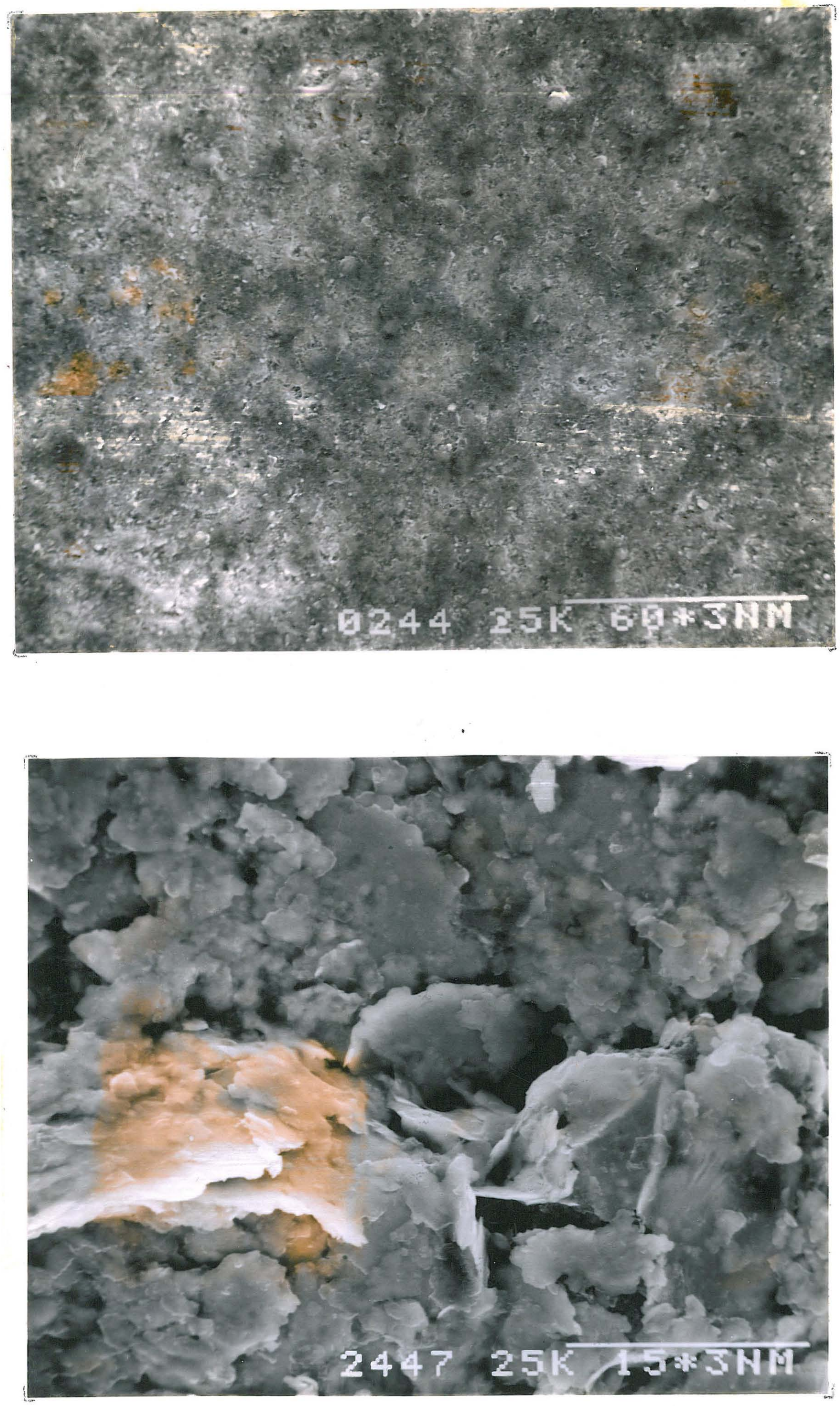


Figure 7. SEM photo of grid-work chert fabric. A) Note light and dark patches, which correspond to extinction units. B) Plates oriented in two mutually perpendicular directions.

disorganization, in terms of crystal orientation and extinction behavior, from the mosaic end-member to the rectilinear grid-work end-member.

Fine-grained materials, predominantly zeolitic and silicate clay inclusions, are present in variable concentrations throughout the groundmass. They can be distributed uniformly in washes (Fig. 8A) or inhomogeneously in clots, and angular to rounded fragments (Fig. 8B & C). In plane polarized light, a wash imparts a uniform tan to brownish color to the chert. Clots are rounded, sub-rounded, ovoid or wispy zones with diffuse edges, that differ in their concentrations of inclusions relative to the surrounding groundmass. Clots are found in most samples and range in size from approximately 160 to 800 μm. Fragments differ from clots in having more distinct boundaries and a greater range of shapes, but they show a similar range of sizes. Angular fragments with outlines that could be fitted back together with nearby fragments and/or groundmass material are present, but rarer than clots. These fragments are most commonly separated by less inclusion-rich cherts or chalcedony. Groundmass of a few samples from location B (Fig. 4) are composed primarily of subrounded to angular fragments (Fig. 8C). Massive groundmass material displays the same chert textures, but is distinct from the clots and fragments because it differs in its concentration of inclusions.

Distinct from the fine-grained inclusions are the carbonate crystals and/or clots of intermediate size, 100-200 μm (Fig. 9). Such carbonates are characteristically found in irregular masses, near the edges of samples and near cracks and voids, and more

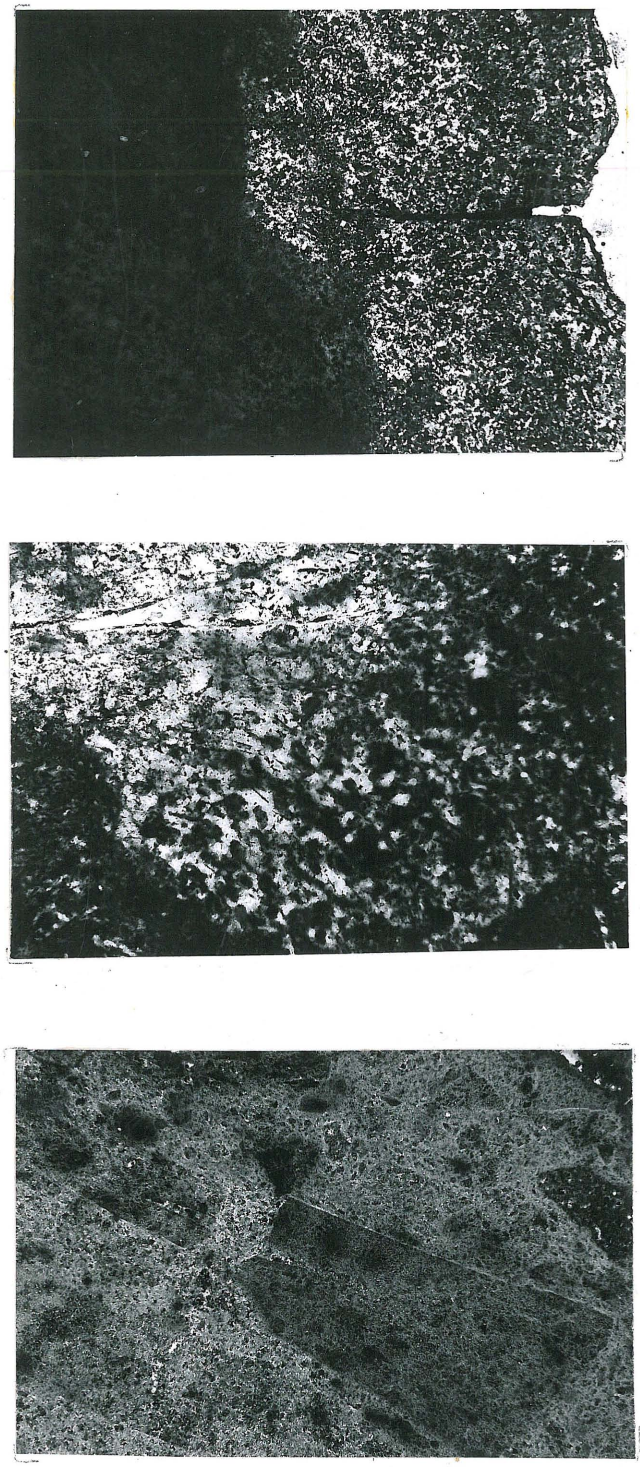


Figure 8. Distribution of inclusions in the groundmass material. A) More inclusion-rich wash inward of the clotted groundmass. Top to right. B) Clotted textures with linear more inclusion-rich zones possible needle crystal molds. C) Large angular fragment that can be fit back together, surrounded by smaller angular to subrounded fragments. Plane light.

Figure 9. Small clots and crystals of carbonate in the groundmass and large, euhedral carbonate crystals in a surface vug. Crossed polars.

rarely, they are scattered throughout the groundmass cherts.

Correlations can be made between the textures of the groundmass and their megascopic appearance. Megascopically the cherts occur along a continuum from powdery to porcelaneous, with an intermediate zone of chalky character (Fig. 10). Both end-members occur in individual samples with powdery material along the rims and porcelaneous chert in the centers, but more commonly, thin inclusion-rich rinds are found on the outer surfaces. Hardness increases along the continuum from powdery to porcelaneous chert. Hardness, along with both the megascopic and microscopic textures, can be correlated with the changing concentration of inclusions. Hardness of the chert varies inversely with the concentration of fine-grained minerals (zeolites, carbonates, and clays). Disorder of the groundmass crystals, as determined by crystal orientation and extinction characteristics, increases with increasing concentrations of inclusions. Rectilinear grid-work cherts are found in the less inclusion-rich porcelanous areas, while the mosaic cherts are more commonly found in the more inclusion-rich chalky and powdery areas.

Cracks, fenestrae, and their filling phases

Most of the samples contain numerous unfilled to partially filled cracks and fenestrae, as well as filled cracks and fenestrae that have been recognized on the basis of similar external morphologies and infilling phases. Cracks are defined as openings that have matching sides and can be fit back together with a minimum of distortion, whereas fenestrae are more

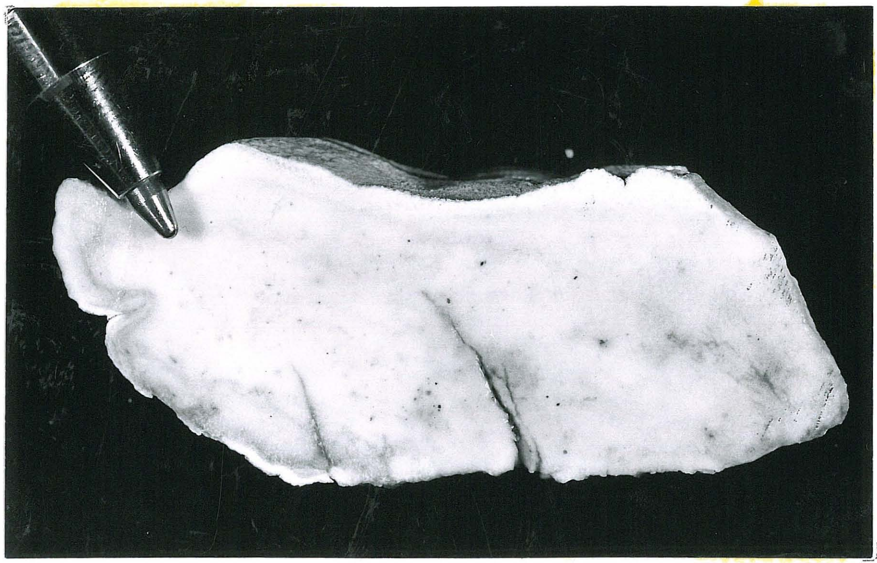


Figure 10. Variability in characteristic of the groundmass at the hand sample scale. Note the change from powdery at the surface through a chalky zone to the porcelanous core.

irregular and have sides that do not match. These two classes are end-members of a continuum. Some cracks and fenestrae are directly connected to the sample edge (peripheral cracks and fenestrae), whereas others are wholly contained within sample interiors (internal cracks and fenestrae). The latter are more common than the former.

Peripheral cracks and their filling phases

Peripheral cracks display a broad range of morphologies and infilling materials. They commonly occur on opposing surfaces of individual samples, propagating inwards at right angles to the surface, are v-shaped, and die out within several millimeters (Fig. 11A). Most peripheral cracks are partially to wholly filled with massive, fine-grained zeolites, carbonates, and/or clays. Such peripheral cracks were referred to as reticulation surfaces by Eugster (1969), and they vary in depth from approximately 600 μm to 8 mm. In plan, cracks can either be aligned to form linear ridges, or link up to form polygons (diameter approximately 1-2 mm)(Fig. 11B).

Less commonly, peripheral cracks are more irregular, propagating in obliquely and forming a dendritic pattern that branches inward and dies out toward the interior (Fig. 12). The boundaries of such cracks are difficult to pinpoint where fine-grained carbonates are abundant in the adjacent groundmass. Such cracks differ from v-shaped cracks in that they are usually filled with a chert as well as zeolites, fine-grained carbonates, and/or clays.

A third type of fenestrae that has a direct outlet to the surface are large pouch-like cavities. These cavities are

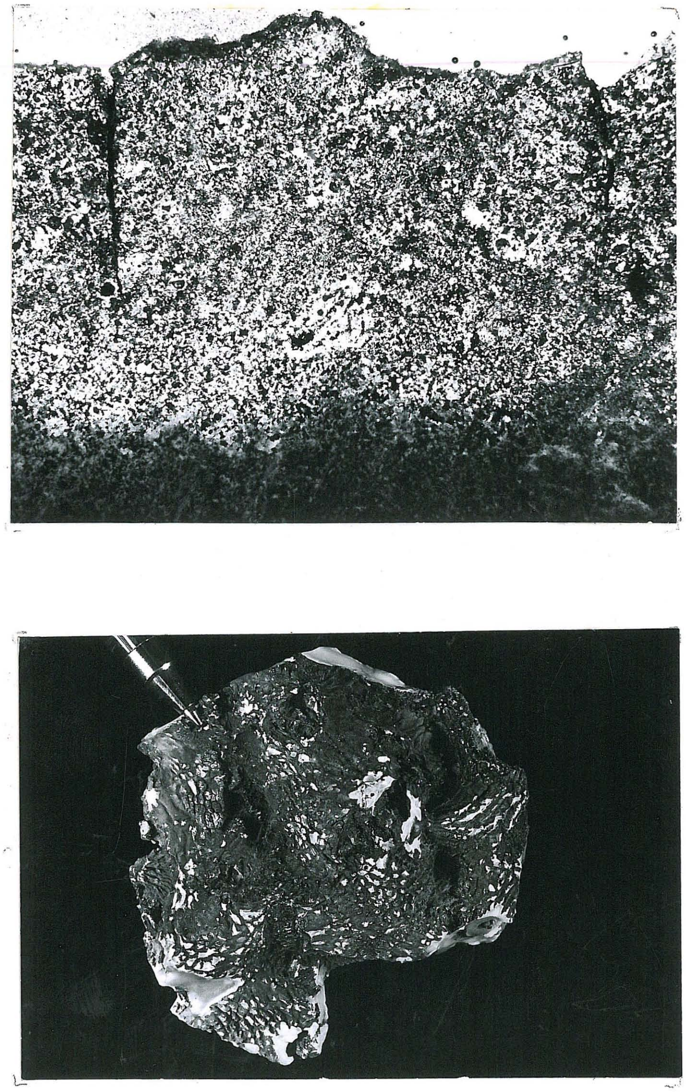


Figure 11. External cracks in cross-section and in plan view. A) Cross-sectional view of v-shaped dewatering dessication cracks. Plane light. B) Surface shot of a reticulation surface.

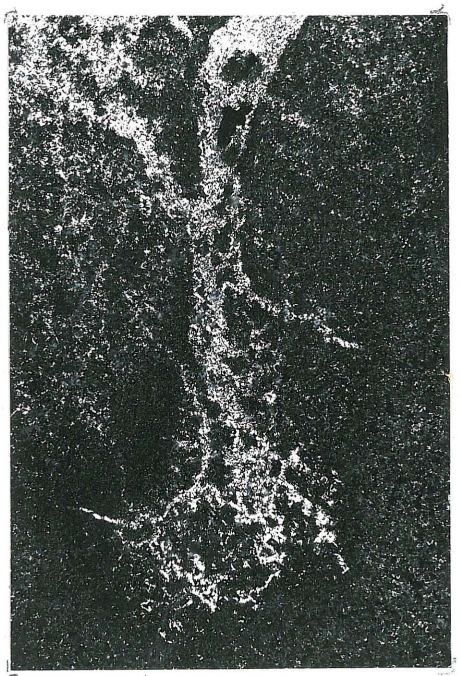


Figure 12. Complex dendritic crack with direct outlet to the edge of the sample. Edge of the sample is just out of the field of view, toward the top.

partially filled with carbonate crystals and form trains on the surfaces of samples, and more rarely within the samples (Fig. 13A). Individual carbonate crystals range in size from 100 μm to 2.8 mm. Some fenestrae propagate in toward the center of the sample, decreasing in size, but becoming more regular and crack-like at their inner limits. Banded material that has green to yellow pleochroism and exhibits parallel extinction (probably illite), along with minor fine-grained carbonates are present as linings of both the peripheral fenestrae and these cracks (Fig. 13B).

Fourth, and finally, there are bedding parallel voids concentrated along thin laminae with high zeolite, carbonate, and/or clay concentrations (Fig 14). They are filled with clays, zeolites, and/or fine-grained carbonates. The clays and zeolites, commonly show a preferred orientation parallel to the walls.

Internal cracks and their filling phases

The majority of the cracks and fenestrae found within the Magadi cherts do not have a direct connection with the outside and are grouped into a volumetrically more extensive internal cracking network. Cracks have been observed under both the petrographic microscope, (Fig. 15A, B, C, D & E), and the SEM (Figs. 16 & 17). The former are more important volumetrically.

Shapes of cracks vary from biconvex to v-shaped. Interconnected cracks form radial, concentric, or stockwork patterns. Internal v-shaped cracks are similar to those on the periphery, with repsect to shape, orientation, and infilling materials. Cracks of this sort are isolated, or found in

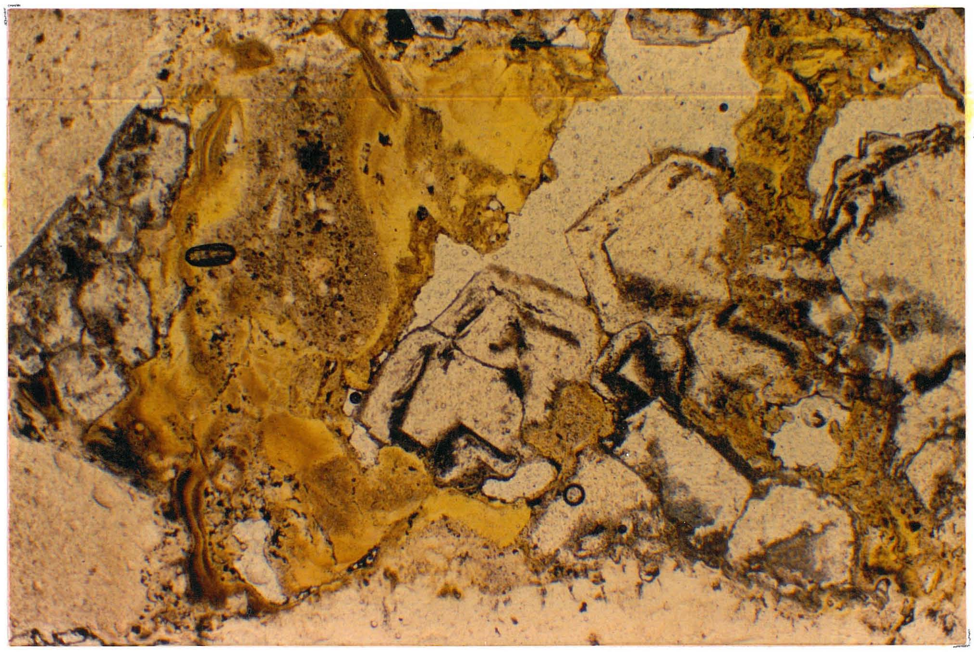


Figure 13. Peripheral pouch-like cavity partially filled with banded illite with admixed fine-grained carbonates and large carbonate crystals.

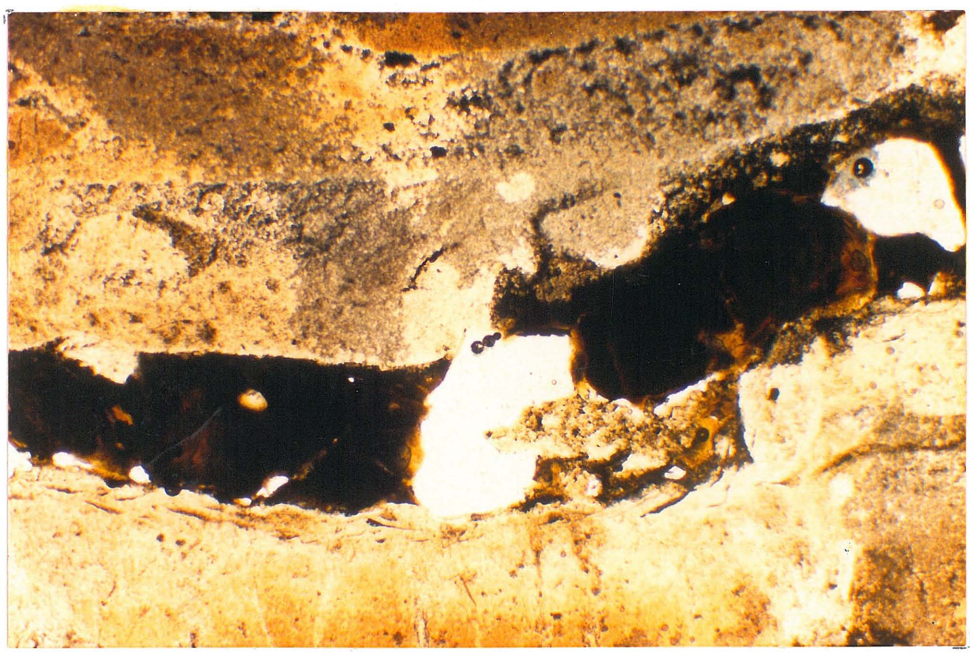
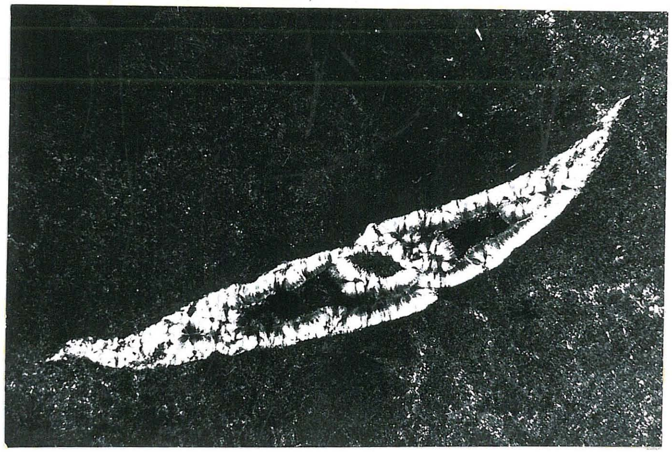
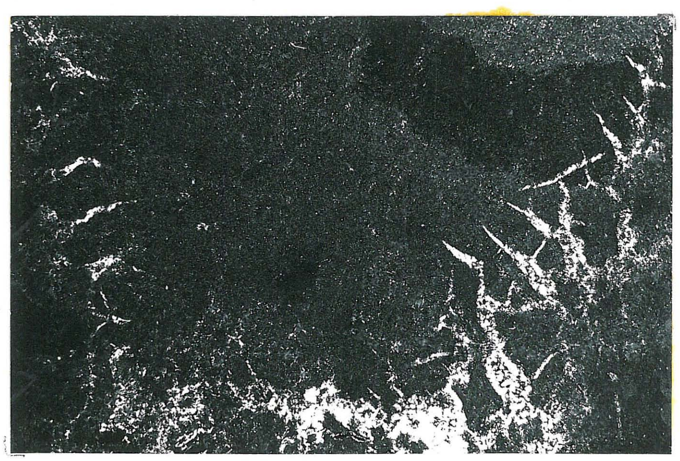


Figure 14. Bedding parallel crack partially filled with fine-grained components. Plane polarized light.





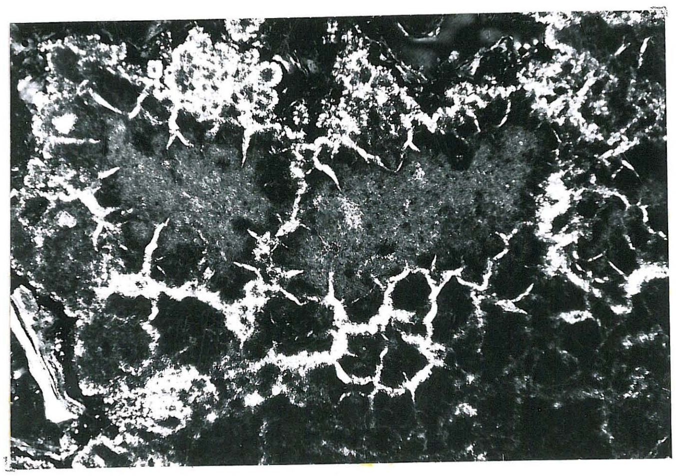


Figure 15. The range of crack morphologies found in the internal crack and fenestrae network. A) Self-contained biconvex body lined with radial fibrous chalcedony. B) Two sets of v-shaped cracks pointing towards each other. Cracks are filled with carbonates, clays and/or zeolites. C) Radial cracks. A set of v-shaped and more complex cracks isolate a body of the groundmass. D) Concentric cracks. E) Stockwork orientation. This combines a number of the previous crack morphologies. Cracks intersect to form a stockwork orientation surrounding the isolated less inclusion-rich zone. Crossed polars.

Figure 16. Radially oriented microcracks. Small hexagonal euhedra are probably analcime.

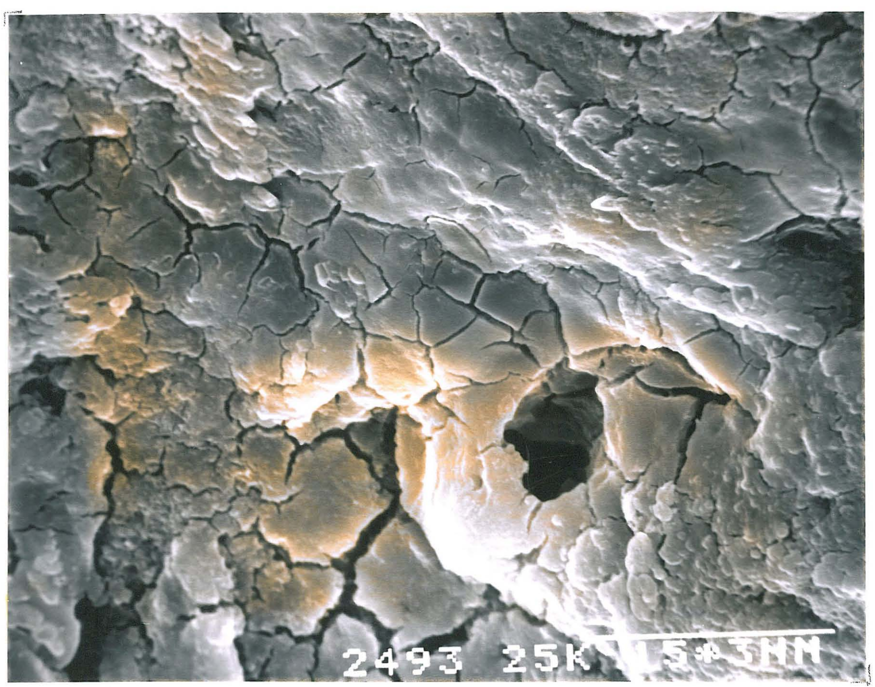


Figure 17. Microcracks divide the groundmass into smaller zones. Sides of the cracks can be matched in many cases.

combination with biconvex cracks or bedding parallel cracks. Some radial crack patterns consist simply of two or more biconvex, or more irregular, intersecting cracks, whereas larger numbers of cracks intersect to isolate blocks of groundmass in places. Rounded inclusion-rich zones are often host to such structures. Concentric cracks typically surround inclusion-rich zones, some of which are dissected by radial cracks. Stockworks differ in that intersecting cracks and fenestrae divide the groundmass into numerous blocks, approximately 200-800 m long. Some cracks are empty whereas others are partially to completely filled with quartz, fine-grained minerals, and/or coarse carbonates, which display a range of textures.

Some cracks have slightly more irregular boundaries, and these pass into fenestrae as the magnitude of the irregularity increases. Highly irregular fenestrae can, for the most part, be divided up into component parts that fit into the documented crack morphologies, save for a large central zone. Mineralogically and texturally the materials filling the fenestrae are very similar to those found in the cracks.

Crack- and fenestra-filling quartz generally takes the form of length-slow chalcedony, but it also occurs as coarse, equigranular chert. Chalcedony is distinguished in hand sample from the groundmass quartz by its translucency and slightly greyish appearance. Partially filled cracks and fenestrae show a botryoidal surface identical to those observed on radial fibrous chalcedony surfaces in geodes. Chalcedony in the Magadi cherts exhibits three types of extinction: 1) radial fibrous, 2) parallel fibrous, or 3) spherulitic (Fig. 18A, B, & C,

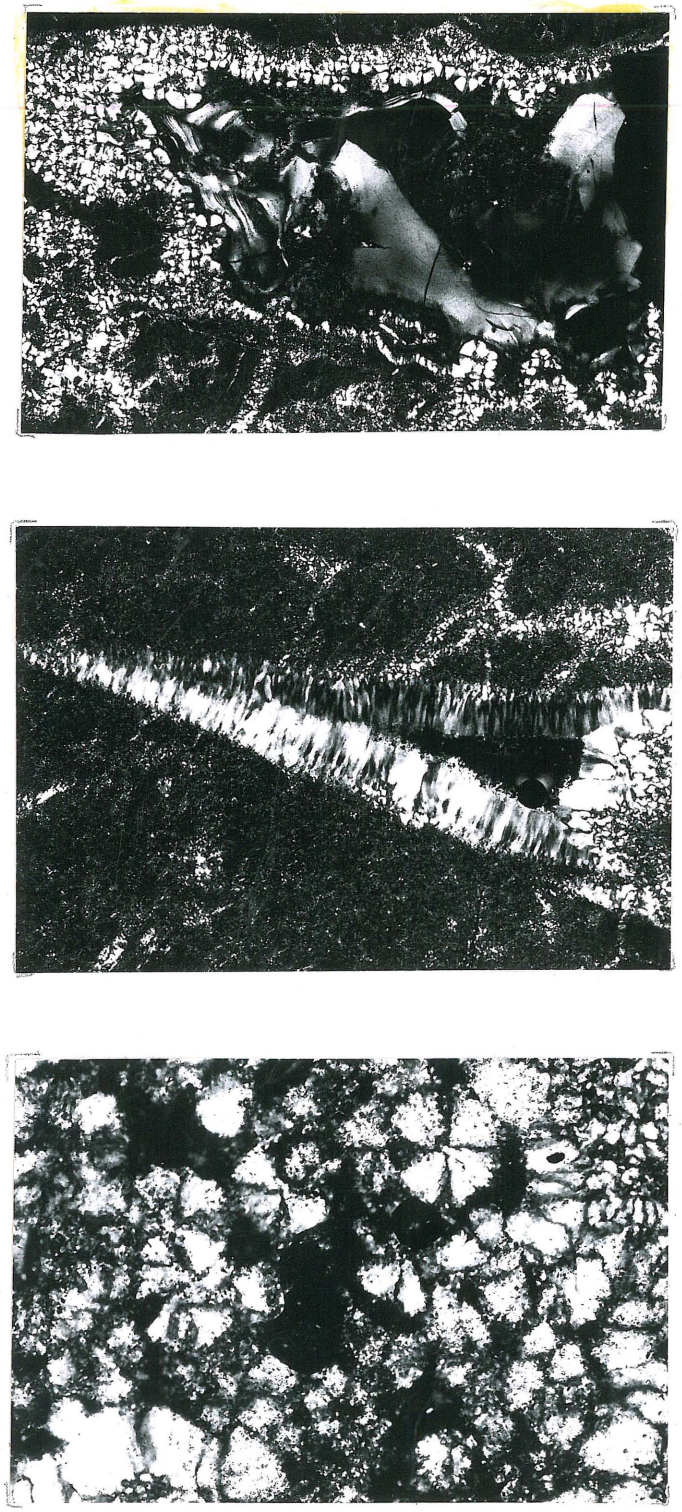


Figure 18. A) Radial fibrious, B) parallel fibrous, and C) spherulitic chalcedony. Crossed polars.

respectively). The differences in the three lie in the radii of the sectors, which depends on the proximity of the fan nuclei.

The chalcedonic aggregates range in radius from 30 to 140 μm, clustering around 70 μm. SEM observation of partially filled cracks and fenestrae shows botryoids with multiple generations of quartz crystals in large fenestrae (Fig. 19), whereas single generations of inward directed chalcedony growth are more common in the cracks and smaller fenestrae (Fig. 20). The quartz crystals range up to approximately 10 m in length, which is much less than the aggregate lengths observed under the transmitted light microscope. Crystals seem to be fan out locally, but not uniformly, as transmitted light microscopy suggests. Aggregates of radial fibrous chalcedony, with partial sectors, meet adjacent aggregates along linear to curvilinear zones. Truly parallel fibrous chalcedony is rare, and grows only on linear substrates, such as crystal molds and in a few linear cracks. Radial to parallel fibrous chalcedony are generally early lining materials in voids that contain no massive zeolites, carbonates, or clays. Multiple generations of chalcedony grow in large cracks and fenestrae. The first generation of growth usually has uniformly spaced nuclei, while nuclei in subsequent generations may be, but are not necessarily, more randomly dispersed. Dominant direction of growth in subsequent generations ranges from perpendicular to almost parallel to the cavity wall. Spherulitic chalcedony (360 sectors) is relatively rare and is restricted to the centers of fenestrae. Triple point junctions are present where partial-sector, substrate-bound chalcedony impinges upon the central, free-floating spherulites, but are not the norm.

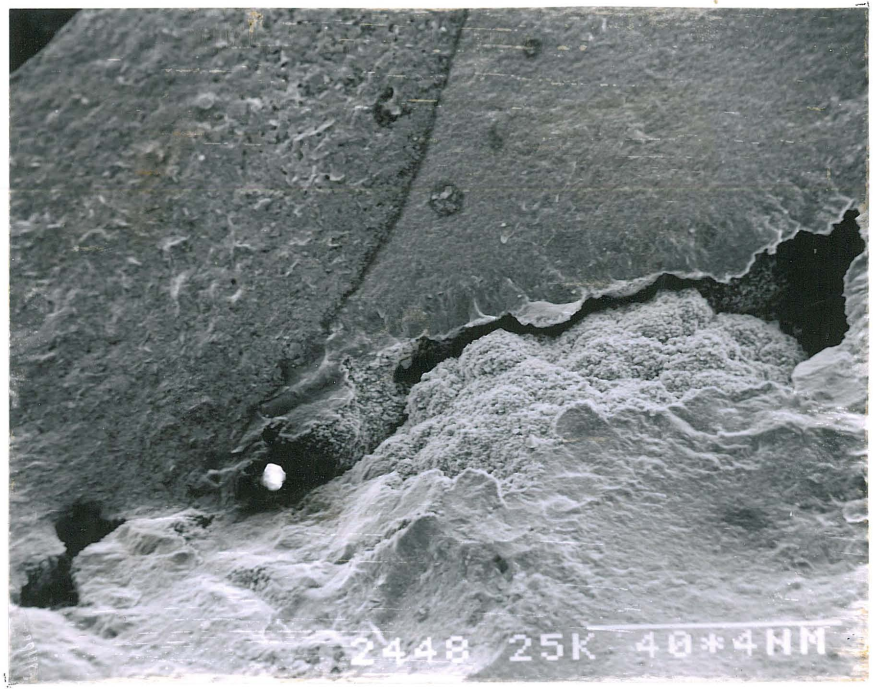


Figure 19. SEM phota of a botryoidal lining in a vug. Botryoids made up of quartz crystals, that look like chalcedony in transmitted light.

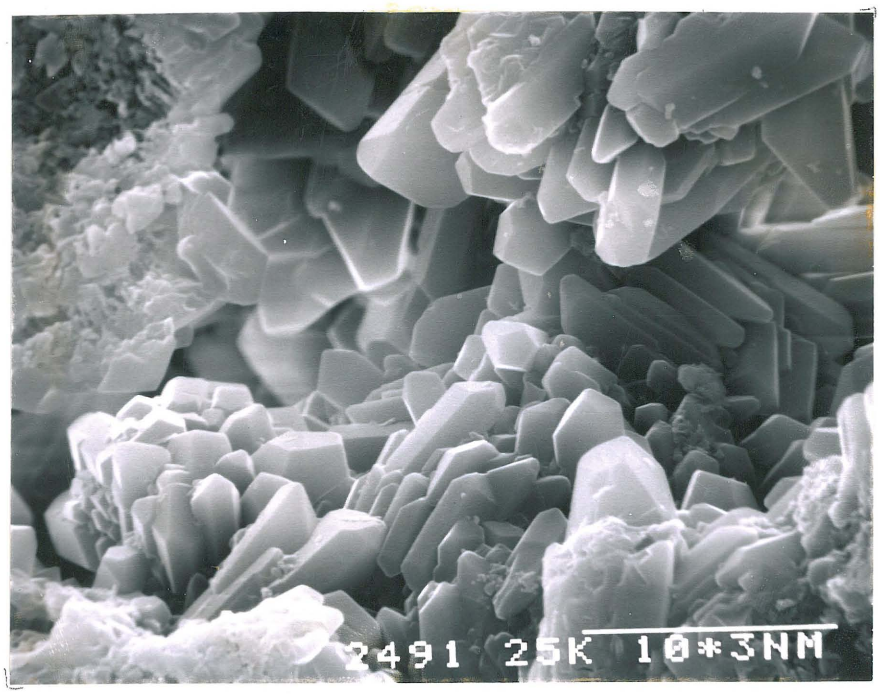


Figure 20. SEM photo of inward directed quartz growth in a small void. Note the local fanning of crystals.

Chert occurs predominantly as a filling in fenestrae, but is also present as a minor crack-filling phase. Fenestrae-filling cherts are most common in the large central zones which taper-out in multiple directions. These cherts are typically less inclusion-rich, and more coarsely crystalline, than the surrounding groundmass cherts.

Fine-grained minerals, most importantly carbonates, are important constituents of the internal crack and fenestra system. Carbonates are found in groundmass material adjacent to cracks and fenestrae that are not lined with chalcedony. Zeolites, carbonates, and clays are found as crack and fenestra fillings, but are less abundant than chalcedony and chert linings and fillings. Fine calcite crystals are also found within the outer fringes of the chalcedony in many cracks and fenestrae.

Large anhedral to euhedral carbonate crystals are present as late-stage fillings in some internal cracks and fenestrae. Such calcite crystals pseudomorph chalcedony fibers and contain isolated sprays of chalcedony in sample M-244 (Figs. 21 & 22). Pseudomorphed chalcedony can be recognized by the presence of regularly distributed inclusions in the carbonate crystals, that are continuous with the textures in the adjacent unreplaced chalcedony. Anhedral calcite fills cracks and some fenestrae, totally. These crystals conform to the shape of the void they are filling.

Crystal Molds

Crystal molds are the rarest of the three textural components that I have identified in the Magadi cherts. They are

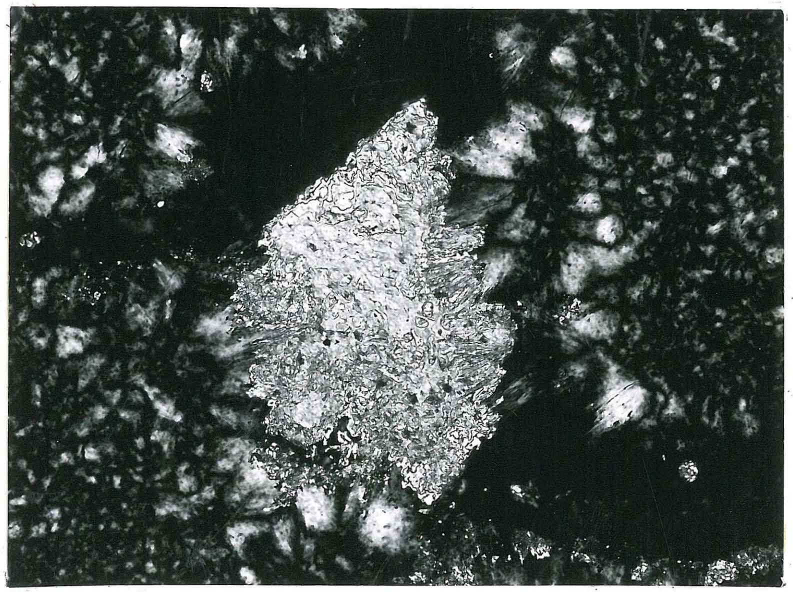


Figure 21. Carbonate replacing chalcedony. The carbonate is pseudomorphing the textures of the chalcedony fibers. Crossed polars.

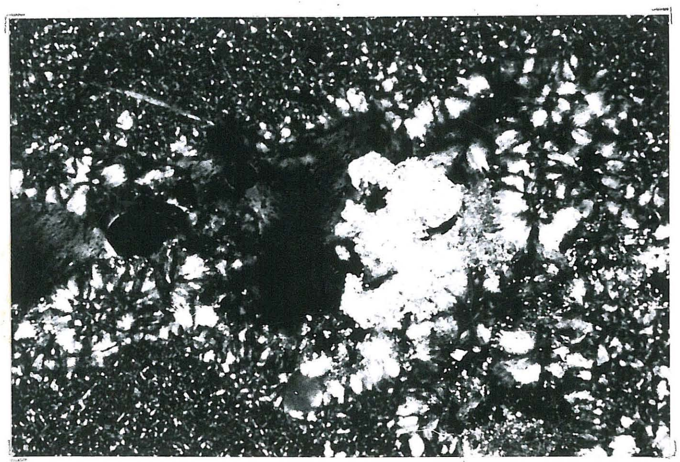


Figure 22. Large carbonate crystal with partial fans of chalcedony preserved within. Carbonate is also pseudomorphing chalcedony fibers on the left edge of the crystal. Crossed polars.

best preserved in the samples that have the greatest volcaniclastic content. A variety of morphologies, sizes and organizations exist. Needle-shaped crystal molds range in length from approximately 320 to 600 μm and occur in randomly oriented masses or as radiating aggregates. Molds with polygonal cross-sections that open to the sample edge are common in some samples (Fig. 23). These crystal molds define linear features on the surfaces of samples. The third, and last easily separable type of crystal molds, are internally contained. These occur as individual crystal molds with either stepped sides or more commonly as six-sided outlines, or in groups that radiate from a center (Fig. 24).

Each type of crystal mold has a characteristic type of infilling material. Most of the needle crystal molds and molds with surface outlets are partially to completely filled with fine-grained materials (carbonates, clays, and/or zeolites). In contrast, most of the large, well preserved, isolated crystal molds are lined with one or more generations of radial fibrous chalcedony, or less commonly, parallel fibrous chalcedony. Complete chalcedony sectors are less common, but occur in the centers of some crystal molds that are lined with earlier generations of partial sector chalcedony. Tips of the chalcedonic quartz are commonly riddled with fine carbonate inclusions. Radiating groups of crystal molds have been noted in one sample, and are partially filled with partial and complete fans of chalcedony.

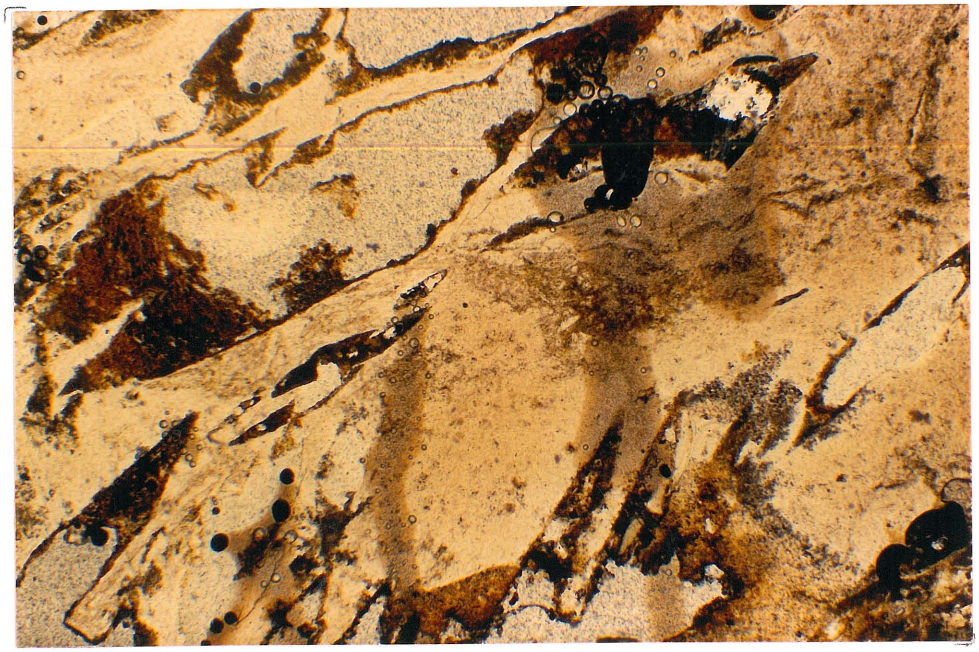


Figure 23. External crystal molds. Note polygonal cross-sections and fine-grained infilling minerals. Plane light.

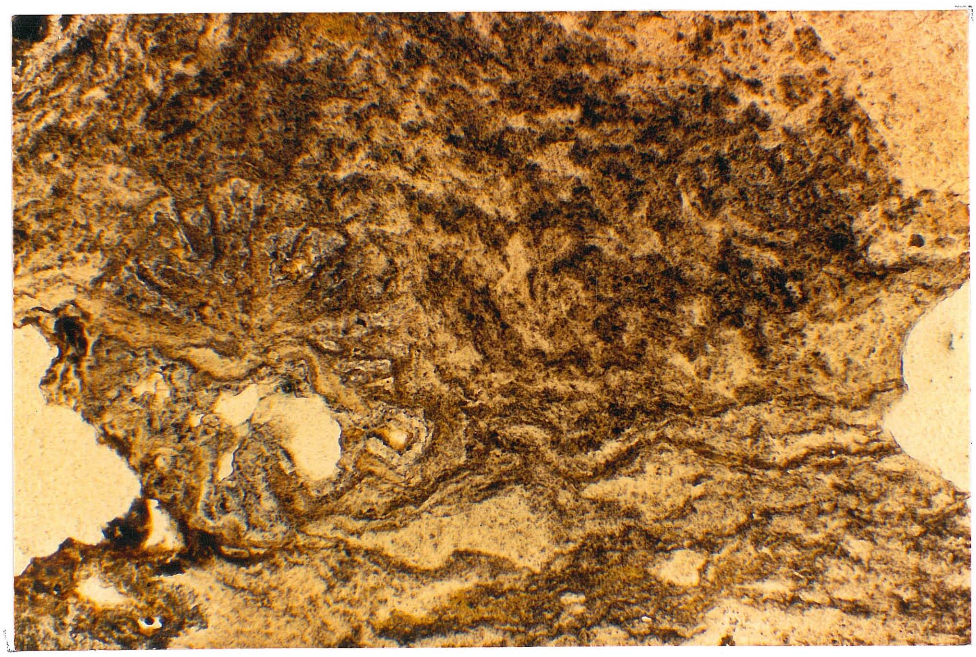


Figure 24. Radial aggregate of crystal molds. Combination of partial and complete chalcedony sectors. Plane light.

INTERPRETATION OF THE MAGADI CHERTS

The Magadi cherts originated as alteration products of the sodium silicate minerals magadiite and/or kenyaite, based on layers of magadiite shallowly buried beneath one or more layers of unconsolidated sediments that can be traced laterally into cherts where the same layers are exposed at the surface. Magadiite is a soft putty-like substance when soaked in brines, but becomes brittle upon drying. It is composed of white spherical bodies made up of intersecting sets of plates, which are approximately 10 to 20 μm in diameter (Fig. 25). In thin section magadiite consists of a mass of interlocking spherulites that form a grid-work extinction pattern (Fig. 26). Layers of both magadiite and chert are found throughout the stratigraphic column, in places adjacent to one another.

Two hypotheses have been set forth to account for the transformation from magadiite to chert: 1) the successive leaching of sodium by percolation of more dilute ground waters (Eugster, 1967, 1969), and 2) a spontaneous transformation in the presence of brines (Hay, 1968, 1970). Whichever mechanism is responsible, the mineralogical transformation from magadiite to chert is accompanied by a minimum 25% volume loss due to the expulsion of Na and H_2O. This loss is thought to be accomodated by a decrease in thickness of the beds, and/or the development of shrinkage cracks and polygons (Eugster, 1969). Thinning of beds is best observed in the field, so the latter will be discussed here. The petrographic data presented in the previous section shed light on the timing and nature of shrinkage and quartz

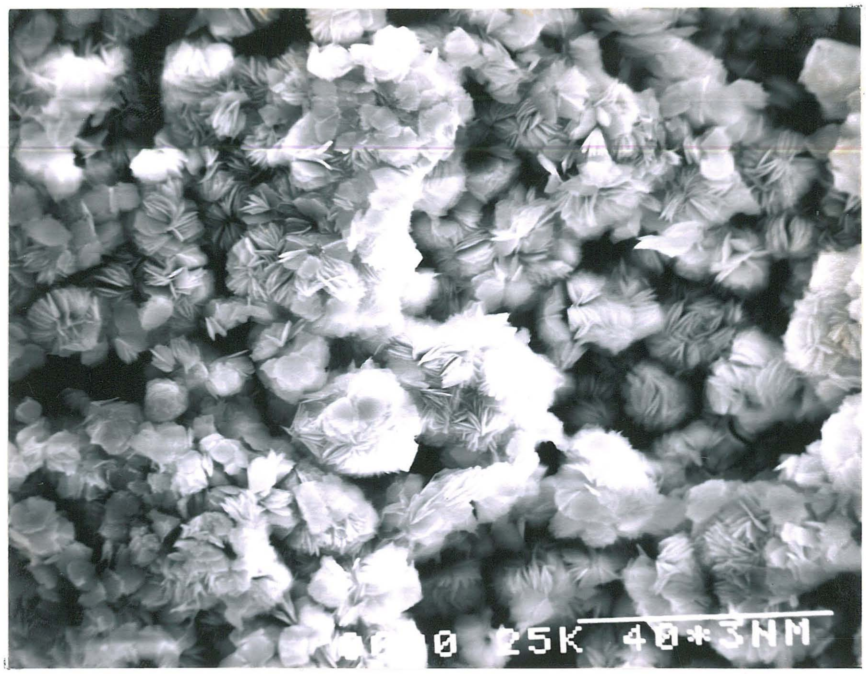


Figure 25. SEM photo of magadiite. Spherulites are composed of interlocking platelets.

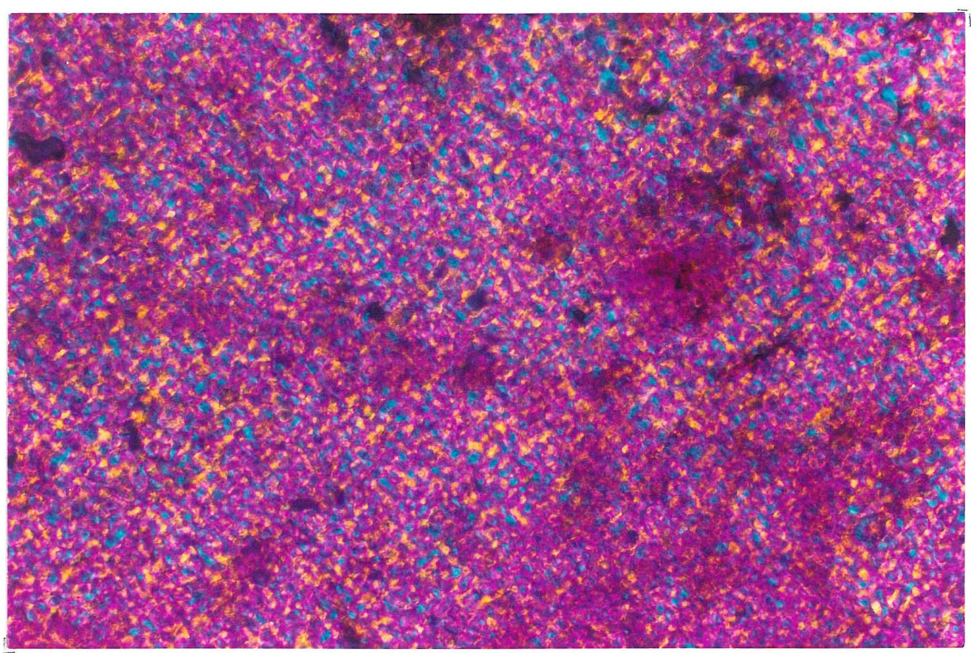


Figure 26. Magadiite with the rectilinear grid-work fabric. Cross-polars with gypsum

crystallization and can be used to test these hypotheses. Moreover, the type Magadi cherts can now be compared to a variety of ancient cherts to see if their textures are unique to cherts formed from sodium silicate precursors in highly alkaline lakes.

Groundmass

The grid-work fabric in the groundmass cherts is similar in both appearance and size of extinction units to that seen in the magadiite, and is probably inherited from it. Often found in the interiors of beds and/or nodules, cherts with the grid-work fabric are farther from potential pathways of water movement, and are inferred to have been less affected by it. Groundmass cherts with the equigranular mosaic fabric, commonly located on the periphery of beds and nodules, are in closer proximity to sources of percolating waters, and are inferred to have been more affected by neomorphism and subsequent precipitation of fine-grained carbonates, clays and/or zeolites. These mosaic cherts have higher concentrations of inclusions which may lend support to their late-stage formation.

Groundmass material of the Magadi cherts is dominantly massive (homogeneous), with variable concentrations of inclusions. Lake-wide chemical precipitation of magadiite, and subsequent in situ conversion to chert should yield a fairly homogeneous product of this sort. Cherts with uniform distributions of inclusions or inclusion-rich clots, in a homogeneous groundmass, fit this scenario.

The variable concentrations of inclusions in some in samples appears to be the product of in situ brecciation. A few samples from location B (Fig. 4) are composed largely of angular, poorly sorted chert fragments that are separated by either ambient groundmass material with variable concentrations of inclusions, coarser-grained cherts, or chalcedony. Such fragments can be fit back together in places, in which case brecciation clearly took place in situ. An autochthonous origin is also inferred for the fragments that can not be pieced back together because: 1) they are texturally and compositionally homogeneous, in relation to each other, and to the surrounding groundmass, 2) they cover a wide range of sizes, and 3) they do not define good self-supporting detrital frameworks. Brecciation probably took place after some chertification because chert textures do not cross-cut fragment boundaries, but the edges of many of the fragments are coated with chalcedony.

Cracks, fenestrae, and their filling phases

Both the internal and external crack and fenestra networks appear to have formed via shrinkage penecontemporaneous with the magadiite to chert transformation(s). Shrinkage features can form as a result of dehydration via a number of different mechanisms. Distinct features presumably form as products of each process, but criteria for differentiating their products are still being developed. The major mechanisms are reviewed in the next paragraph, and possible criteria for distinguishing their products are enumerated.

Subaerial dessication of wet mud involves the evaporation of water, leading to the formation of mud or sun cracks at the sediment/air interface. Suncracks, in their simplest form, are v-shaped in cross-section and form polygonal patterns in plan-view, but their morphologies can become quite complex by repeated wetting and drying of the surface (Smoot, unpublished). Detrital infilling from above is another important characteristic of suncracks (Smoot, unpublished). Colloidal substances, or gels, can form syneresis cracks via water expulsion, either subaerially or subaqueously. Dewatering of gels may produce cracks that extend to bedding surfaces or are internally contained. Cracks formed in Precambrian iron-formations (Simonson, in press; Simonson and Lanier, in press) have been attributed to true syneresis. Such cracks are filled with a combination of void-filling crystals and internal sediments. Subaqueous cracks of uncertain origin in sediments or crystalline materials also display a wide range of morphologies. Subaqeous cracks form in flocculated clay suspensions in response to drastic salinity changes (Burst, 1965). Some of these cracks are v-shaped in cross-section, and similar in morphology to subaerial dessication cracks (Burst, 1965). Septarian veins, formed in many concretions via shrinkage (Raiswell, 1971; Lindholm, 1974; Boles et al., 1985), are characterized by large central zones with marginal radiating cracks that taper out towards the edges of the concretions. Septarian cracks typically form a stock-work and are filled with cements.

The fact that v-shaped cracks and associated reticulation surfaces occur on opposing surfaces of individual samples of Magadi chert indicates that these are not simple suncracks, but probably form as a result of dewatering of a hydrous phase during neomorphism. Morphologically these external cracks are most similar to dewatering cracks in flocculated clay suspensions (White, 1961; Burst, 1965; Donovan and Foster, 1972). The internal cracks in the Magadi cherts most closely resemble septarian veins morphologically. Similarities include the presence of stockworks, the lack of detrital infilling, and the fact that cracks and fenestrae in the Magadi cherts frequently decrease in size toward the edges of the samples. These similarities that the cracks and fenestrae formed as a result of the water loss that accompanies the transformation from magadiite to chert.

Chalcedony can grow as a result of competetive growth during void-filling precipitation (Grigor'ev, 1965), or via the replacement of carbonates (Wilson and Pittman, 1971). I interpret the chalcedony in the Magadi cherts as a void-filling precipitate based on the outward directed growth of aggregates off of substrates, and partial infill of many cracks and fenestrae. Parallel fibrous chalcedony is only found lining crystal molds and on rare occasions linear cracks. Although spherulitic chalcedony generally forms via replacement, I interpret spherulites in the Magadi cherts as void-filling precipitates, based on their presence in the central regions of voids that are lined with one or more generations of void-filling cements. This may have been made possible be repeated nucleation events, by analogy to spherulitic aggregates of Mg-calcite (peloids) described by MacIntyre (1985).

Most of the chalcedony in the Magadi cherts is length-slow, the presence of which, has been attributed to the silicification of evaporites (Folk and Pittman, 1971; Wilson and Pittman, 1971; Siedlecka, 1972; Milliken, 1979). The Magadi occurrences do not fit the pattern in that waters rich in sulphate and magnesium are thought to be responsible for length-slow chalcedony formation (Kenne, 1983), yet sulphate and magnesium concentrations do not vary sympathetically during evolution of the Lake Magadi brines. Brines in present-day Lake Magadi are depleted in magnesium and enriched in sulphate, but high concentrations of magnesium are never reached in either the lake waters or the more dilute source waters. Therefore length-slow chalcedony may precipitate in highly alkaline lake waters via quite different mechanisms.

Carbonate minerals are a late-stage phenomena that precipitate after the formation of chert and chalcedony. Several lines of evidence support the late-stage formation of carbonates: 1) occurrence as a final lining material in many fenestrae, 2) presence as large crystals in otherwise empty cracks- and fenestrae, 3) replacement of virtually all other phases, and 4) thin calcite coatings on outer surfaces of samples. Carbonates are found in cracks and fenestrae, along the edges of samples, and near the periphery of cracks and fenestrae, indicating that that their distribution is linked to easy access of percolating waters.

It is unclear from available evidence whether illite is authigenic or detrital in origin. Clays found in the large external cracks, fenestrae and crystal molds are commonly banded and show a strong preferred crystallographic orientation, which could result from either authigenic or illuvial origin, however, clays in these same zones appear to be geopetally distributed and contain admixed minor silt-size detritus, favoring a detrital origin. Smaller cracks, both internal and external, are commonly filled with massive clays and/or zeolites, so their origins are not easily resolved. In summary, some of the illite in the Magadi cherts appear to be detrital in origin, while the origin of other occurrences are still of uncertain origin.

Zeolites are found throughout the samples, both within the groundmass, and in internal and external cracks and fenestrae. Zeolites are rarely detrital because they are so highly reactive and form only over a very limited range of conditions (Hay, 1966). However, no new evidence was uncovered to directly confirm or refute this for the Magadi chert samples studied.

Crystal molds

Crystal molds are well preserved overall, but are usually best preserved in the interior. Preservation of euhedral molds suggests that the deposits have not been subjected to extensive weathering since initial dissolution of the crystals. Crystal molds were filled via the same processes as cracks and fenestrae because infill in both the internal and external features of each category (cracks and fenestrae, and crystal molds), are similar, with predominantly carbonates, zeolites and/or clays in the external features, and chalcedony dominating in the interior. Crystal molds are thought to be dissolved out trona crystals, that were precipitated in the brines (Hay, 1968), based on the presence of hexagonal cross-sections. The nature of the filling suggests that the crystals both precipitated and dissolved out prior to chertification.

Transformation from magadiite to chert

It is important to look at five processes and the features that form as a result, in trying to determine the mechansim responsible for the magadiite to chert transformation. These processes, listed in the order in which they are inferred to have taken place, are: 1) shrinkage and the formation of cracks and fenestrae, 2) dissolution of large euhedral crystals and the formation of crystal molds, 3) chalcedony growth, 4) authigenic mineral growth and/or emplacement, and 5) carbonate and clay growth and/or emplacement.

The hypotheses set forth by Eugster (1967;1969) and Hay (1968, 1970) can now be examined in light of the petrographic data. Eugster (1969) uses lateral changes from magadiite to chert in a single near-surface bed to infer that the former is the precursor material of the latter. Hay's (1968) model of a spontaneous transformation in the presence of brines is also supported by field data, including the fact that chert deposits are found in the center of the ancient High Lake Magadi, and crystal molds, probably trona, are present in the cherts (Hay, 1968, 1970). The occurrences of chert and magadiite beds throughout the stratigraphic column raises doubts about both proposed mechanisms. Additional field work is clearly needed to resolve some of these questions.

Most of the petrographic and mineralogical evidence I've gathered seems to indicate that brines have been important in shaping the Magadi cherts, and circumstantial evidence suggests that they may have been the medium responsible for the transformation from magadiite to chert. Shrinkagae features, formed penecomtemporaneously with the magadiite to chert transformation closely resemble subaqueous dehydration cracks and account for the 25% volume loss that accompanies the magadiite to chert transformation. Standing brines are more likely to provide an effective medium in which to form subqueous dessication cracks than ephemeral streams. A 38% solution of NaOH is released in the transformation, which may have been responsible for the formation of the well preserved crystal molds through trona dissolution (Hay, 1968). The presence of analcime, a moderate salinity authigenic mineral, and albite and potassium feldspar, high salinity authigenic silicates, also supports the presence of brines. Because shrinkage cracks and fenestrae seem to have formed subaqueously, and the East African Rift Valley has been getting drier for at least the last 10,000 years, making major lake level fluctuations inprobable, I contest that the magadiite to chert transformation took place in the presence of lake brines. Carbonates are late-stage precipitates, and are more likely formed by waters other than the lake brines, which are calcium depleted.

I think that both processes, set forth as being responsible for the transformation, probably played a role, but the spontaneous transformation in the presence of brines seems to be most important in the samples that I studied. Textural evidence indicates that the Magadi cherts formed via a complex series of events which began with the precipitation of magadiite and culminated in zeolite, carbonate, and/or clay precipitation and/or deposition.

COMPARISON OF MAGADI CHERTS WITH ANCIENT CHERTS

Background information

I have looked briefly at a number of cherts from different periods of geologic history to see how they compare texturally with the Magadi cherts. The ancient cherts range in age from Early Cenozoic to Archean, and come from shallow to deep marine and lacustrine environments (Table 3). Petrographic comparisons will serve as a preliminary test of the validity of using textural criteria in recognizing 'Magadi-type' cherts. If the proposed textural criteria are diagnostic of the type Magadi cherts, and this type of chert can be recognized confidently, it will be possible to make important paleoenvironmental interpretations based on a fairly small number of samples.

The most distinctive features of the Magadi cherts are: 1) the presence and concentration of inclusions, 2) the shapes, orientations, and infilling phases, of cracks and fenestrae, 3) the occurrence of other late-stage mineral phases (i.e. replacive carbonates), and 4) the presence of crystal molds. These textural and mineralogical characteristics can be used as indicators of processes active at the time of formation, and the geochemistry of the waters responsible for the transformation from magadiite to chert. The chert samples studied for comparison will be discussed with these characteristics in mind.

TABLE 3

ANCIENT CHERTS

AGE (geologic period)	LOCATION (geographic)	FORMATION	TYPE OF CHERT (Env. of dep.)
Paleocene-Eocene	Lake Flagstaff, Utah	Flagstaff	Replacive (lacustrine)
K-T	Costa Rica	Sabana Grande	deep marine
Mesozoic	Costa Rica	Nicoya complex	deep marine
Mesozoic	San Francisco, California	Franciscan complex	biogenic (deep marine)
Mesozoic	British Columbia	Cache Creek	deep marine
Devonian	Iowa City, Iowa	Cedar Valley	Replacive (distal shelf)
Ordovician	Edna Mountain, Nevada	Vinini	deep marine
Late Proterozoic	Svalbard	Rysson	Replacive (tidal flat)
Proterozoic	Hamersley Basin, Western Australia	Marra Mamba Fe-fm	distal shelf/ basinal marine
Proterozoic	Hamersley Basin Western Australia	Mt. Sylvia	distal shelf/ basinal marine
Proterozoic	Hamersley Basin, Western Australia	Mt. McRae shale	distal shelf/ basinal marine
Early Proterozoic	Schefferville area, Labradour trough	Sokoman	shallow marine
Archean	Vermillion Range N. Minnesota	Soudan Fe-fm	deep marine

Description of ancient cherts

Radiolarian cherts

Deep sea radiolarian cherts are commonly composed of equigranular mosaics of quartz crystals with radiolarian tests interspersed. A few samples have ambient groundmass material in which individual crystals are too fine to resolve, but show an overall preferred orientation, akin to the rectilinear grid-work fabric documented in the Magadi cherts. The groundmass material in individual deep sea radiolarian chert samples commonly show one of the two end-member textures found in the Magadi cherts, but not both.

Inclusions, of unknown composition, are common in the groundmass of many radiolarian cherts, and range from simple washes to clotted textures. Inclusions in the radiolarian cherts, however, never define fragments. Composition of the inclusions in the deep sea cherts would aid in interpreting the mechanism and environment of their formation.

Cracks are commonly present in the radiolarian cherts, and are far more abundant than fenestrae. Orientations are numerous and varied, and include: 1) bedding parallel, 2) bedding perpendicular, and 3) bedding oblique. Cracks in the radiolarian cherts are extensive and are not usually internal. Linear cracks commonly extend the length of the thin section. Infilling materials are predominantly quartz or carbonate, with the former being more prevalent. Quartz infillings take on one of four habits: 1) fibrous, 2) microcrystalline 3) drusy, or 4) blocky. These occur in various combinations, though they tend to shift from fibrous to blocky towards the center of the crack.

Carbonate-filled cracks are less common than quartz-filled cracks but are still an important constituent in some radiolarian cherts. Blocky carbonate crystals are found either in the centers of quartz lined cracks or totally filling cracks. There is evidence (pseudomorphed chalcedony fibers) that some of the carbonate is replacing the earlier chalcedony linings.

Carbonate-replacive cherts

Cherts replacing two marine and one lacustrine carbonate were studied (Table 3). I will discuss the marine examples first. The groundmass in the marine cherts is characterized by equigranular mosaics of quartz crystals with uniformly distributed carbonate inclusions that represent relicts of the carbonate precursors. Small hairline fractures are present, but rare, in these marine cherts, and have been largely overprinted by chertification. Large vugs are present in some of the less completely replaced zones, and are partially to wholly filled with single carbonate crystals or length-slow chalcedony.

Lacustrine cherts from Lake Flagstaff, Utah occur largely as replaced carbonate peloids, skeletal fragments, or cements. Most of the samples show either detrital frameworks of carbonate peloids with quartz cement, or silicified skeletal fragments interspersed with fine-grained carbonate sediments. Fine-grained carbonates are partially to largely replaced by equigranular mosaics of chert in some sections, but carbonate inclusions are still widespread. Fenestrae are widespread, and like the pore space, are generally filled with quartz cements. Cements are chalcedonic (length-fast) or blocky.

Iron-formation cherts

Cherts from the Hamersley Basin iron-formations are characterized by microbands (mm-scale) and mesobands (cm-scale) (Trendall, 1973). Textures of the groundmass cherts lie on a continuum from equigranular mosaics to domains. Domain textures, a term used by Simonson (1985) in describing chert textures in the Wishart Formation, are groups of crystals that exhibit undulatory, almost spherulitic extinction. Some samples have finer-grained inclusions, but they are predominantly coarser-grained than those found in the Magadi cherts and are composed of oxide minerals, riebeckite, and carbonate.

Bedding-parallel and -perpendicular cracks are common in iron-formations. Bedding perpendicular cracks are generally long and linear, and cut across both iron-rich and chert-rich beds. These cracks may be tectonic in origin, and unrelated to depositional or lithification processes. They are filled predominantly with blocky quartz. Found at the interface between chert-rich and oxide-rich laminae, bedding parallel cracks are commonly filled with drusy quartz. Fenestrae are self-contained units with simple shapes ranging from self-contained biconvex bodies to sub-rounded zones. Fenestrae, like the cracks, are filled mainly with blocky quartz.

Crystal molds are present as a minor component in the Hamersley Basin iron-formation samples that I looked at, and are filled predominantly with blocky quartz.

Cherts from the Sokoman iron-formation are similar to the

Hamersley Basin cherts in many respects. Sokoman cherts are fairly homogeneous, inclusion-poor, and show equigranular mosaic to domain textures. Both internal and external cracks and fenestrae are present in these samples, and occur at various angles to bedding. Quartz is the main infilling mineral and takes on a variety of forms: 1) fibrous, 2) drusy, and 3) blocky. Drusy and blocky quartz appear quite convincingly to be void-filling phases. This is not always true of the chalcedony, which is not easily distinguishable from the groundmass in plane polarized light.

Textural comparison of the Magadi cherts with other ancient chert

None of the cherts, marine or lacustrine, that I studied were good textural matches for the Magadi cherts. The Magadi cherts possess a set of textural characteristics that make them unique and allow them to be distinguished from all of the other cherts I examined as follows:

1) Groundmass textures that lie along a continuum from rectilinear grid-works to equigranular mosaics.

2) Associated inhomogeneities of inclusions and chert textures, especially washes, clots, and angular fragments, that can be correlated with groundmass textures and megascopic features. Internal inclusion-poor porcelanous zones with grid-work textures, and peripheral inclusion-rich equigranular mosaics.

3) An external cracking network that is present on opposing surfaces of samples and defines surface reticulation patterns. These cracks are commonly filled with massive

zeolites, carbonates, and/or clays.

4) An extensive internal cracking network that is partially to completely filled with predominantly chalcedony, with minor carbonates, zeolites, and/or clays.

5) Euhedral crystal molds that were formed during the magadiite to chert transformation. The external molds are commonly filled with carbonates, zeolites, and/or clays. Internal molds, like the internal cracks and fenestrae, however, are more commonly filled with chalcedony, and have a minor proportion of fine-grained components.

6) Moderate- to high-salinity zeolites/feldspars.

7) Late-stage illites.

8) Late-stage carbonates.

Textural characteristics reflect the geochemical and physical parameters operating at the time of chert formation, and as such, should differ in cherts that form via different processes (Table 4). Groundmass textures in the ancient cherts generally lie on a continuum from equigranular mosaics, with point extinction, to spherulitic figures. The rectilinear grid-work fabric, common in the Magadi cherts, is only rarely found in the deep sea radiolarian cherts and is never found in the other ancient cherts. Compositions of the inclusions in the ancient have not been determined, but distributions of inclusions are potentially important in trying to understand paragenetic sequences. Inclusions in the deep sea radiolarian cherts show clotted textures and uniform inclusion washes, but overall fine-grained inclusions are much less abundant in the ancient cherts. Cracks are fairly abundant in the cherts used for comparative

TABLE 4

COMPARISON OF TEXTURES BETWEEN THE
MAGADI CHERTS AND ANCIENT CHERTS

TEXTURAL CHARACTERISTIC	TYPE OF DEPOSIT MAGADI	RAD.	CARB-REPLACED	IRON-FM.
GROUNDMASS				
1) Equigranular mosaic	*	*	*	*
2) Grid-work	* *	o	-	-
3) Domain	-	-	-	*
INCLUSIONS				
1) Wash	* *	+	-	-
2) Clots	* *	+	*	-
3) Fragments	*	-	-	-
CRACKS AND FENESTRAE				
1) External v-shaped	*	-	-	-
2) External dendritic	+	-	-	-
3) External cavities	++	-	-	-
4) Bedding parallel	o	*	-	*
5) Bedding perpendic.	-	*	-	*
6) Internal v-shaped	+	-	-	-
7) Internal biconvex	* *	o	o	+
8) Linear, bed. oblique	-	*	+	+
9) Internal fenestrae	* *	o	+	+
10) Hairline cracks	-	*	o	+
INFILLING PHASES OF CRACKS AND FENESTRAE				
1) Clays	*	-	-	o
2) Zeolites	*	-	-	o
3) Carbonates	*	+	*	o-+
4) Chalcedony	* *	*	*	*
5) Drusy quartz	-	*	*	*
6) Blocky quartz	-	*	*	*
CRYSTAL MOLDS	+	+	o	o

- absent o-rare +-present *-abundant

purposes, but are more laterally extensive, widely separated, and are often systematically oriented in space. Fenestrae in the ancient cherts are less abundant, and have more regular (ovoid) shapes than the irregular fenestrae that characterize the Magadi cherts. Phases that line or fill the cracks and fenestrae in both the Magadi cherts and ancient cherts display many of the same compositions and textures. One feature, widespread in all other cherts, but nonexistent in the Magadi cherts is the presence of blocky and drusy quartz as a component of crack and fenestrae fillings. Differences between the Magadi cherts and other ancient cherts lie predominantly in organizations of features, and existence of textures that run the gamut of those present in the Magadi cherts.

While the Magadi cherts share some similarities with ancient cherts of both marine and lacustrine origin, their complete textural signature is unique, and allows its use as a test for their recognition. Each deposit carries a textural signature that represents the conditions of the environment in which it formed and processes active after its deposition (i.e. diagenesis).

SUMMARY

In this study I documented the textural characterisitcs of and paragenetic sequences within the Magadi cherts, then compared them to other, ancient cherts. The Magadi cherts, form as a result of the alteration of sodium silicate minerals, magadiite of kenyaite. Most of the textural features, i.e. groundmass, cracks and fenestrae, and crystal molds, probably form during the transformation. The presence and composition of minor mineralogical components, i.e. zeolites, can be used to place constraints on the compositions of the waters responsible for their transformation, and the presence of clays and carboantes can be used to infer the chemistry of the waters that formed these later phases.

The lack of any good textural correlation between the Magadi cherts and those used for comparison supports the use of petrography as a test for the recognition of 'Magadi-type' cherts. Conversely, textures in the Magadi cherts may not survive diagenesis, so care needs to be taken in identifying 'Magadi-type' cherts solely on the basis of textures. If the textures survive diagenesis, it appears that 'Magadi-type' cherts are rare in the geologic record.

To elucidate the processes active in Magadi chert formation and to further test the use of petrography as a tool for the recognition of 'Magadi-type' chert in the ancient, further field-work should be undertaken in the Lake Magadi area, Kenya. To facilitate recognition of 'Magadi-type' cherts in the ancient it is particularly important to study lacustrine cherts of probable 'Magadi-type' origin that are of intermediate age.

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